AFOSR – Theoretical, Numerical, and Experimental Investigations of the Fundamental Processes that Drive Combustion Instabilities in Liquid Rocket Engines
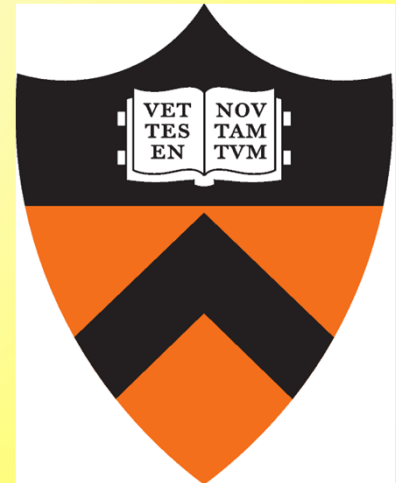
Program Update

Matt Quinlan, Yong Jea Kim, Martina Baroncelli, Ciprian Dumitrache, Hongfa Huo, Xingjian Wang, Vigor Yang and Ben T. Zinn

Guggenheim School of Aerospace Engineering

Georgia Institute of Technology

C. K. Law and V. Akkerman

Department of Mechanical & Aerospace Engineering

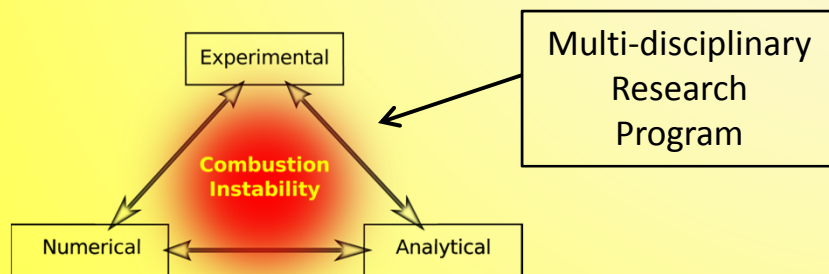Princeton University

September 13th, 2012

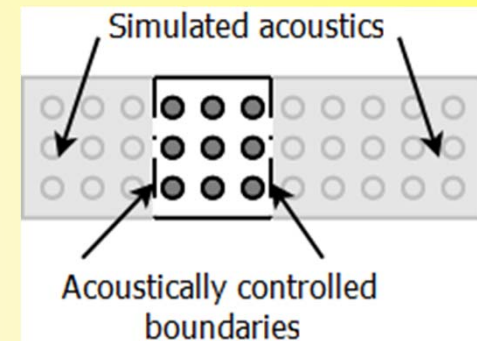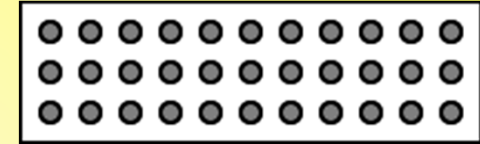| 1. REPORT DATE **13 SEP 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Program Update**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Institute of Technology,Guggenheim School of Aerospace Engineering,Atlanta,GA,30332**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the 2012 AFOSR Space Propulsion and Power Program Review held 10-13 September in Arlington, VA. U.S. Government or Federal Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

The Actively Controlled LRE Simulator (ACLRES) Concept
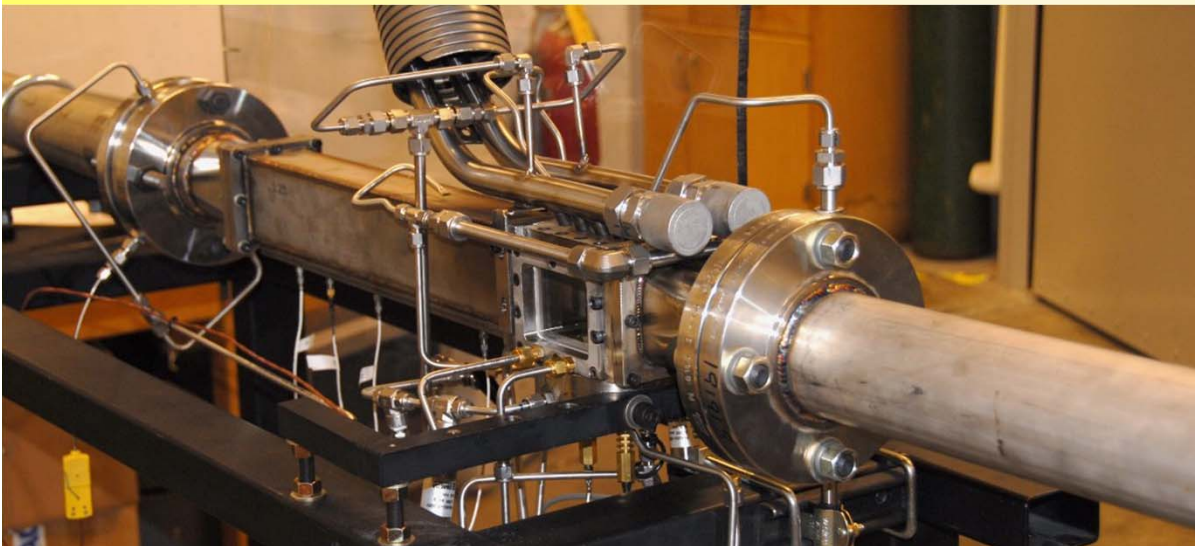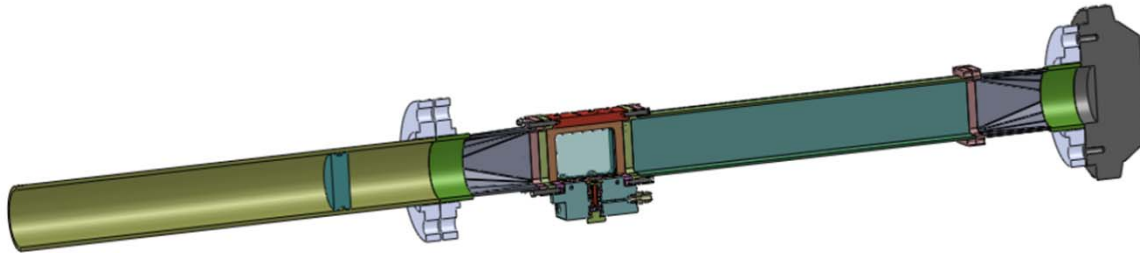

Acoustically controlled boundaries
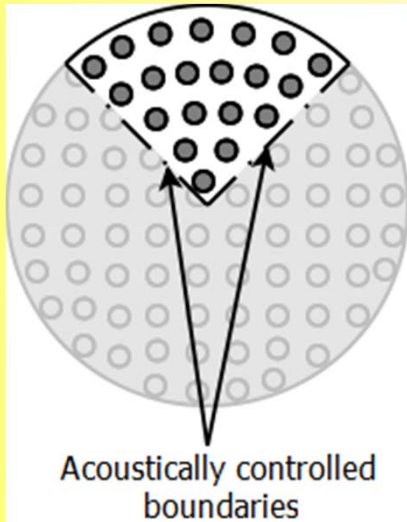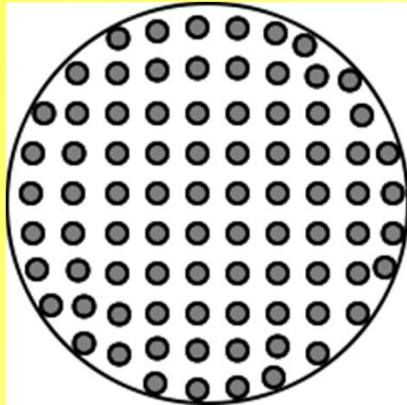
- Testing full scale cylindrical or two dimensional LRE is very costly

- The acoustic environment within any section of a full scale LRE is controlled by the acoustic impedances on its boundaries

- For simplicity, the proposed small scale rig concept is being demonstrated on a 2-D rig that can also experience transverse instabilities

- The boundary impedances in the small scale rig are actively controlled by speakers

Simulated acoustics

Acoustically controlled boundaries

Experimental

Combustion Instability

Numerical   Analytical

Multi-disciplinary Research Program

Actively controlled, 2-D, ACLRES

9/13/2012
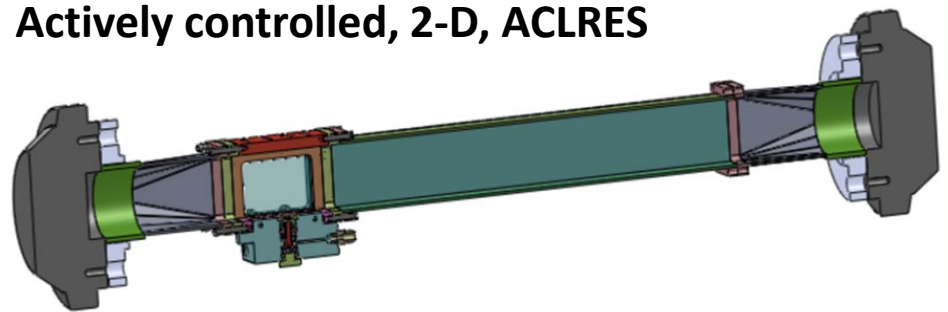
Actively controlled LRE Simulator (ACLRES)
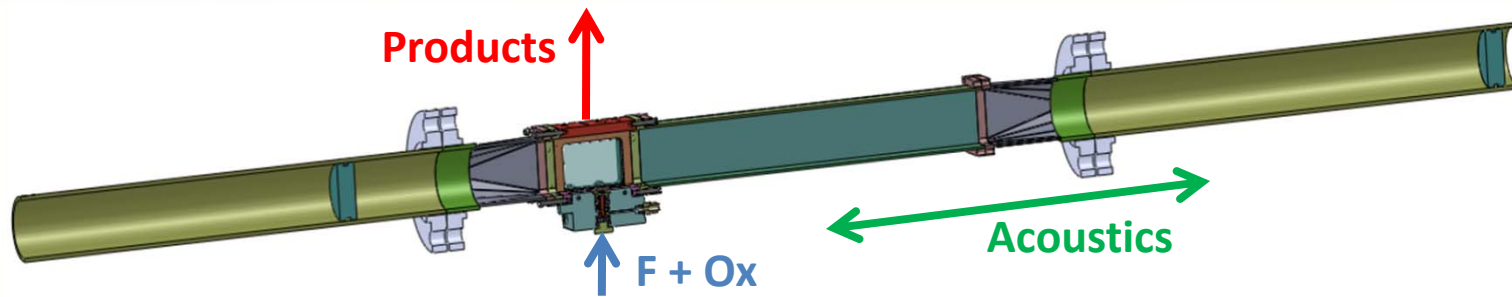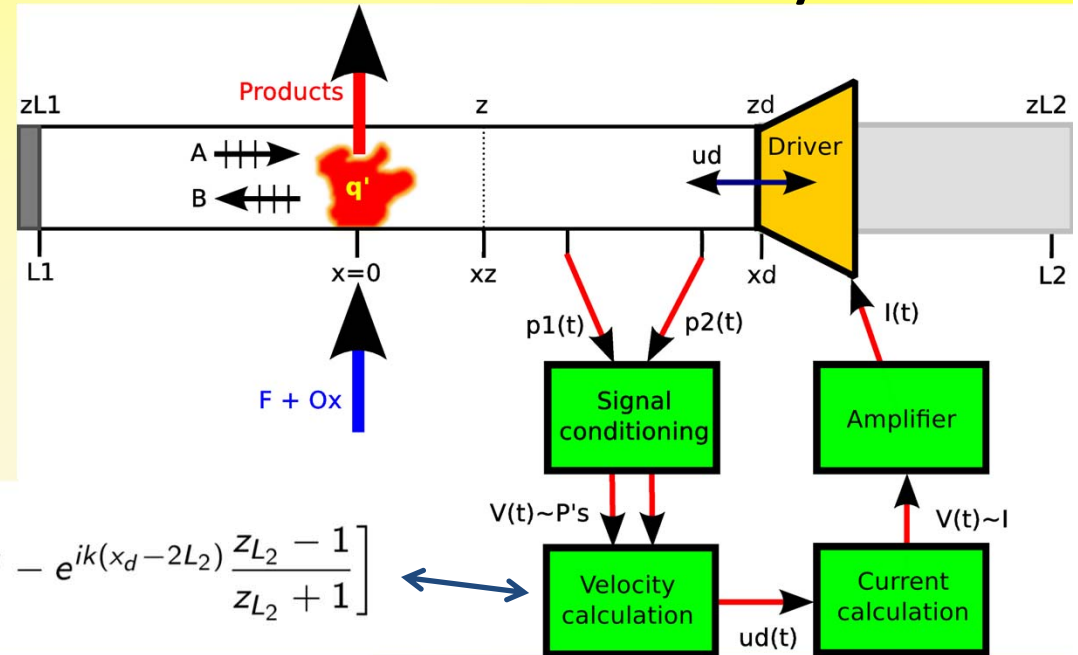

- Active control of boundary impendence capabilities
- Excites transverse acoustics (instabilities)
- Has access for optical diagnostics
- Injector plate may be interchanged to allow investigation of the driving by different injection systems
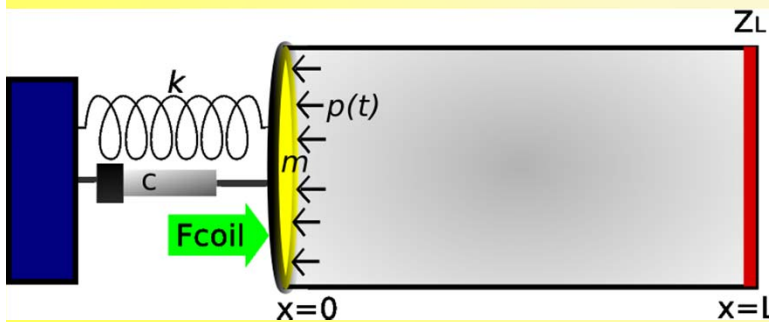
3

Development of the ACLRES Active Control System

- The ACLRES system

- Acoustic model
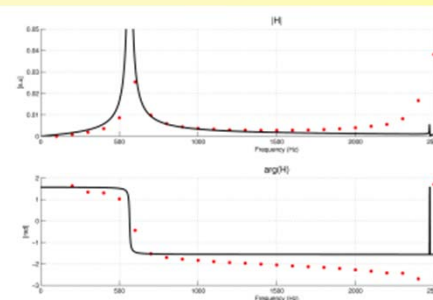

$$u_D(t) = \frac{i\,[p_2(t) - p_1(t+\tau)]\sin(\omega\tau)e^{ikx_1}}{\rho c\,[1 - \cos(2\omega\tau)]}\left[e^{-ikx_d} - e^{ik(x_d - 2L_2)}\frac{z_{L_2} - 1}{z_{L_2} + 1}\right]$$

- Speaker model (transfer function)

Speaker test rig

$$I(t) = u_d(t)\frac{\left[i\omega m + \frac{\kappa}{i\omega} + \nu + \frac{(N\pi dB)^2}{Z_{el}} + Z_{Md}\right]}{G_{amp}N\pi dB}$$

Preliminary Results

- The "Full scale" LRE tested to identify its instabilities (~170 Hz)

- Investigated the acoustics of the ACLRES rig (~250 Hz)

- The ACLRES (using one injector and combustion) was actively controlled to excite full scale LRE instabilities in the rig

- The "full scale" engine instabilities and the ACLRES natural acoustic modes were excited in the first test
  - Need to "remove" the ACLRES natural modes in future tests

- Modeling efforts show the mean flow controls the spinning instability
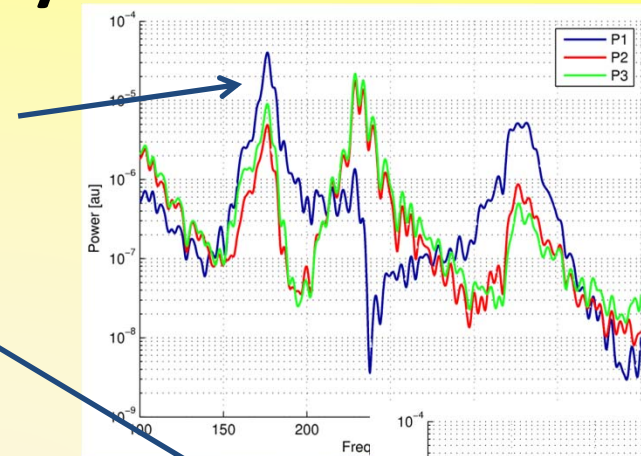
Acoustic PSD
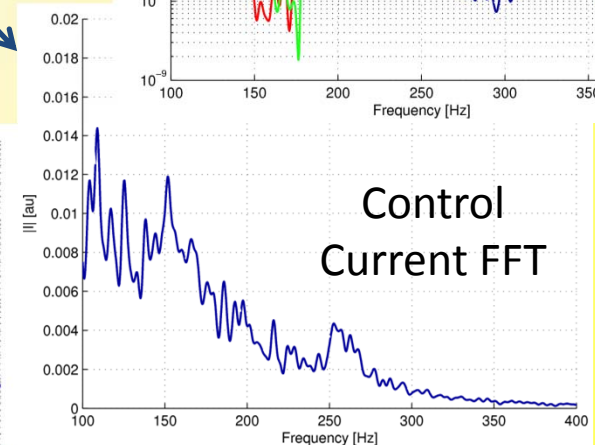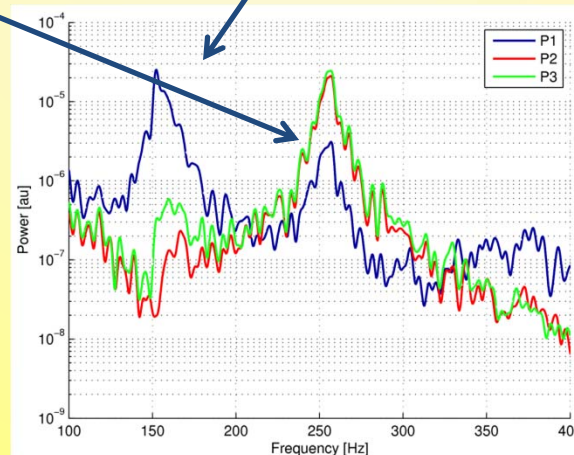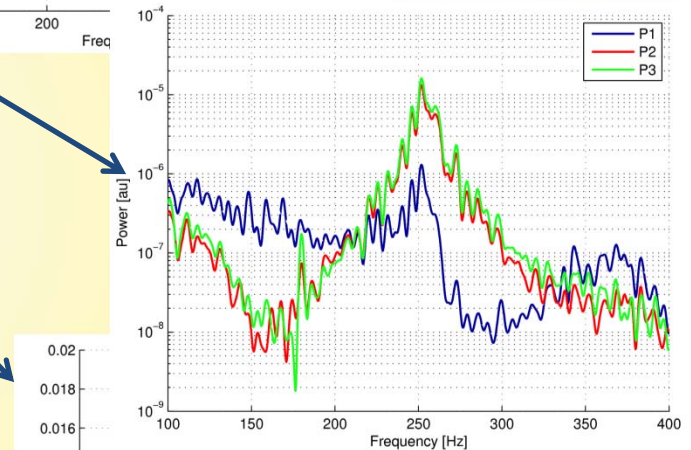
Control Current FFT

Interest and Governing Physics

Explore role of stability of
nozzle-generated triple flame on LRE
combustion instability

- Stabilization through premixed
  flame segment =>
  - Chemistry inherently important
  - Prone to exhibit flamefront
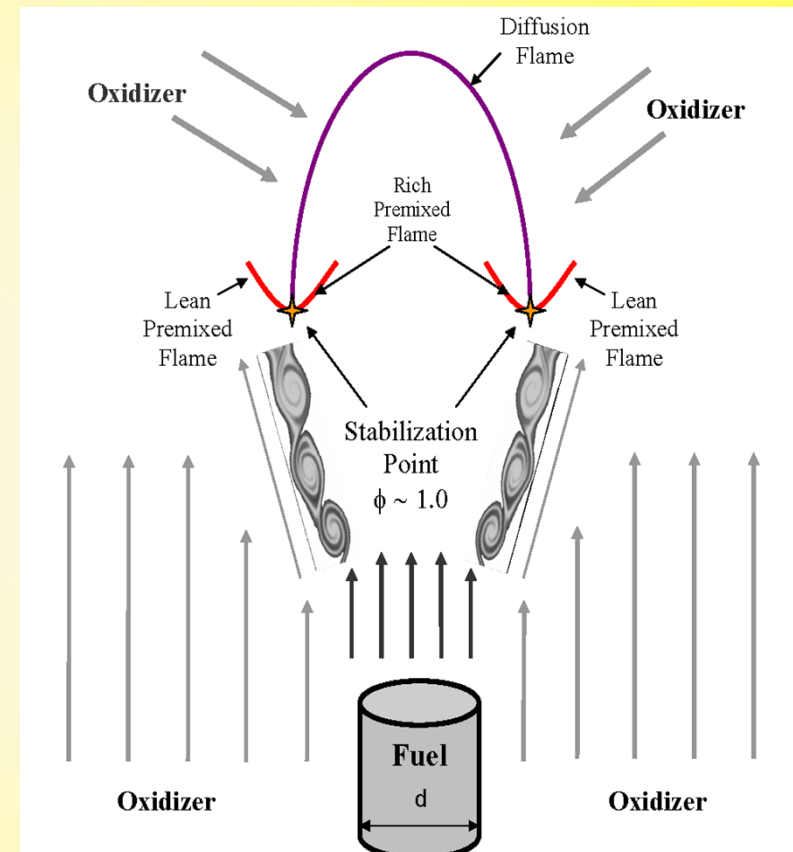   instability
- Bulk flame is still diffusion
  controlled
  - Source of heat release
  - Also prone to flamefront instability
  - Couples to chamber acoustics

Various Intrinsic and Acoustic Flamefront Instability Modes

Instability Mode	Premixed Flame	Diffusion Flame
Rayleigh-Taylor (RT)	Yes	Yes
Diffusional-thermal (DT)	Pervasive, ↓ as p ↑	Near-limit situations
Darrieus-Landau (DL)	↑ as p ↑ and δ ↓	No
Kelvin-Helmholtz (KH)	?	Yes
/////////////////////////////	/////////////////////////////	/////////////////////////////
Acoustical / Parametric	Yes	Yes

Instability Modes Analyzed

❑ Nonpremixed flame segment

   ➢ Rayleigh-Taylor, Kelvin-Helmholtz

❑ Acoustic-flame interaction

   ➢ Resonantly stabilizing but parametrically destabilizing

❑ Stability domains

   ➢ Landau limit

   ➢ Finite flame thickness

High-Fidelity Modeling and Simulation of Liquid-Propellant Combustion at Supercritical Conditions
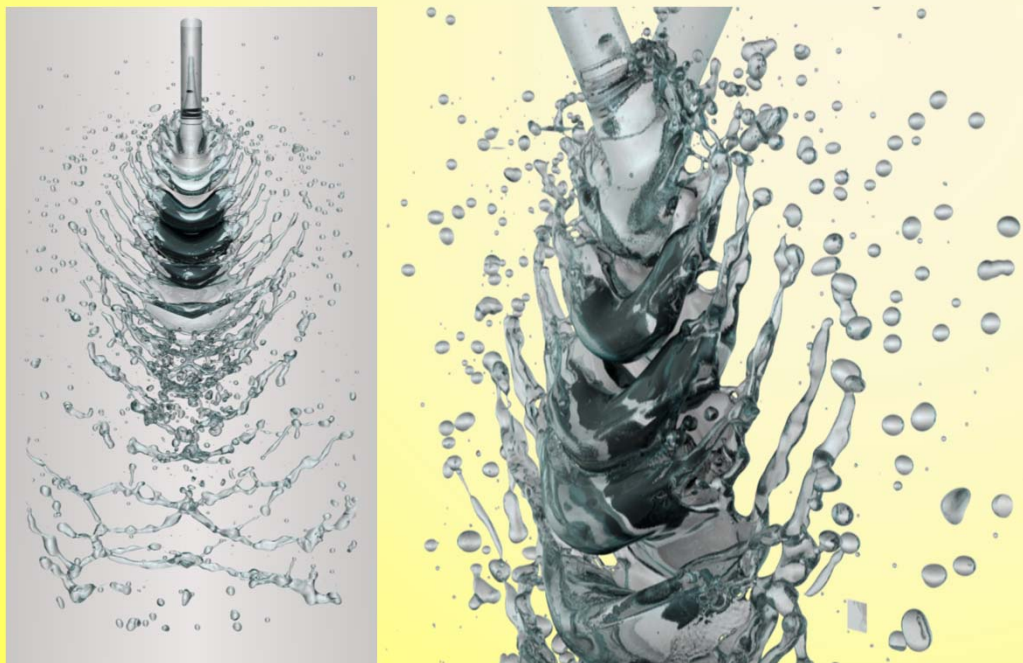
- **Objective of Research**: To develop an integrated theoretical and computational framework for treating combustion dynamics of cryogenic and hydrocarbon propellants under conditions representative of contemporary liquid rocket engines

- **State of the Art of Research**: Limited research on high-fidelity modeling and simulation of (1). turbulence-chemistry interactions at supercritical conditions; (2). supercritical combustion of hydrocarbon propellants (some progress made for cryogenic propellants); (3). swirl injector flow dynamics (only classic theories available); (4). liquid-liquid injector flame dynamics; (5). injector flow response to external forcing.

- **Advancements of Current Research**: (1). Establishment of a unified theoretical-numerical framework for treating supercritical combustion over entire fluid thermodynamic states; (2). study of swirl injector flow dynamics at supercritical conditions; (3). study of swirl injector combustion of hydrocarbons; (4). study of swirl injector flow response to acoustic excitations.

Research is currently undergoing to establish this correction.

ACCOMPLISHMENT 1

(1) high-fidelity, quantitative knowledge of liquid propellant combustion dynamics at practical engine operating conditions; (2) identification of key design attributes and flow conditions dictating injector behaviors; (3) reduced-base modeling for data presentation and knowledge synthesis.
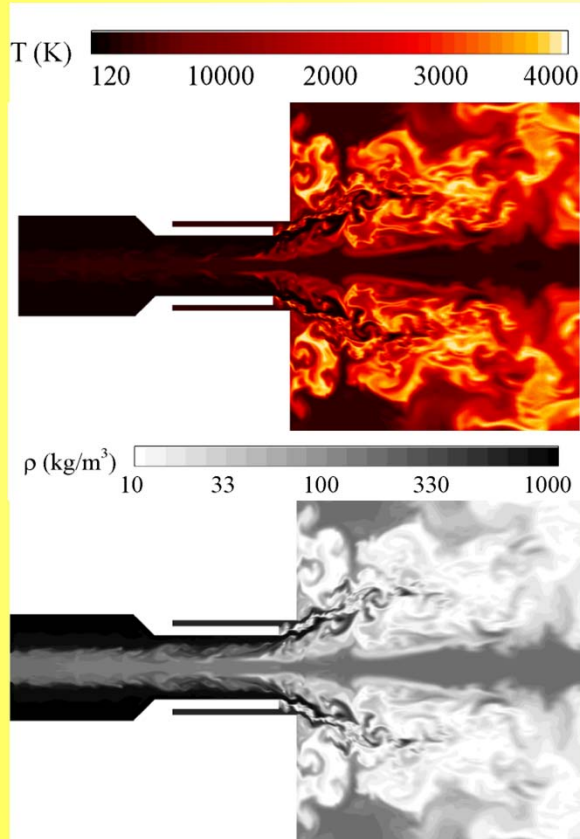
DNS/LES of LOX-Methane Flames
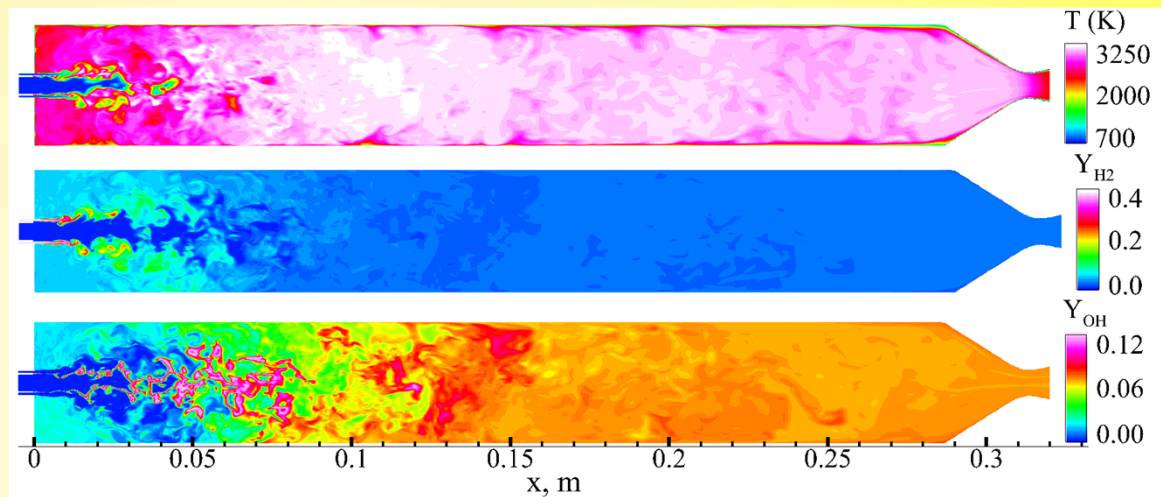

Multi-Phase Flow Dynamics
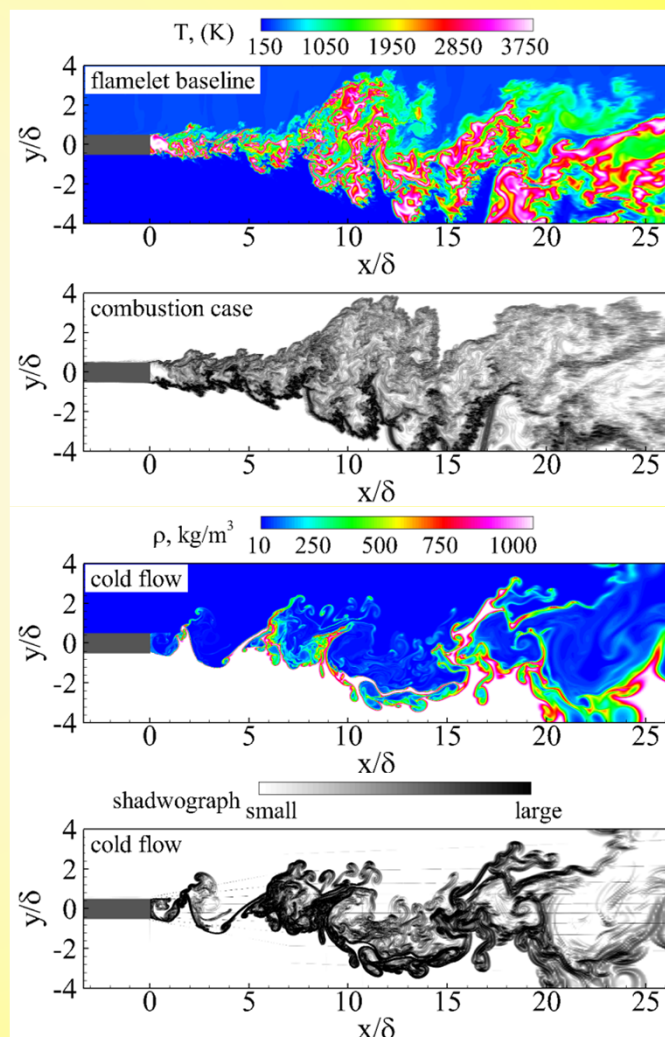
ACCOMPLISHMENT 2

Identification of key injector design attributes and flow conditions for engine performance improvement and combustion instability mitigation

snapshots of temperature, and mass fractions of H2 and OH of GO2/GH2 shear co-axial injector flames

instantaneous temperature and density contours of LOX/kerosene double swirl injector flame

LES techniques developed to address critical development issues of liquid rocket combustion devices

- injector dynamics
- chamber cooling
- wall compatibility
- combustion instability